



The Orbital Debris Problem and the Challenges for Environment Remediation

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Outline

- **What is orbital debris?**
- **How much orbital debris is in space?**
- **Danger of orbital debris**
- **Challenges to preserve the near-Earth space environment**



What Is Orbital Debris?



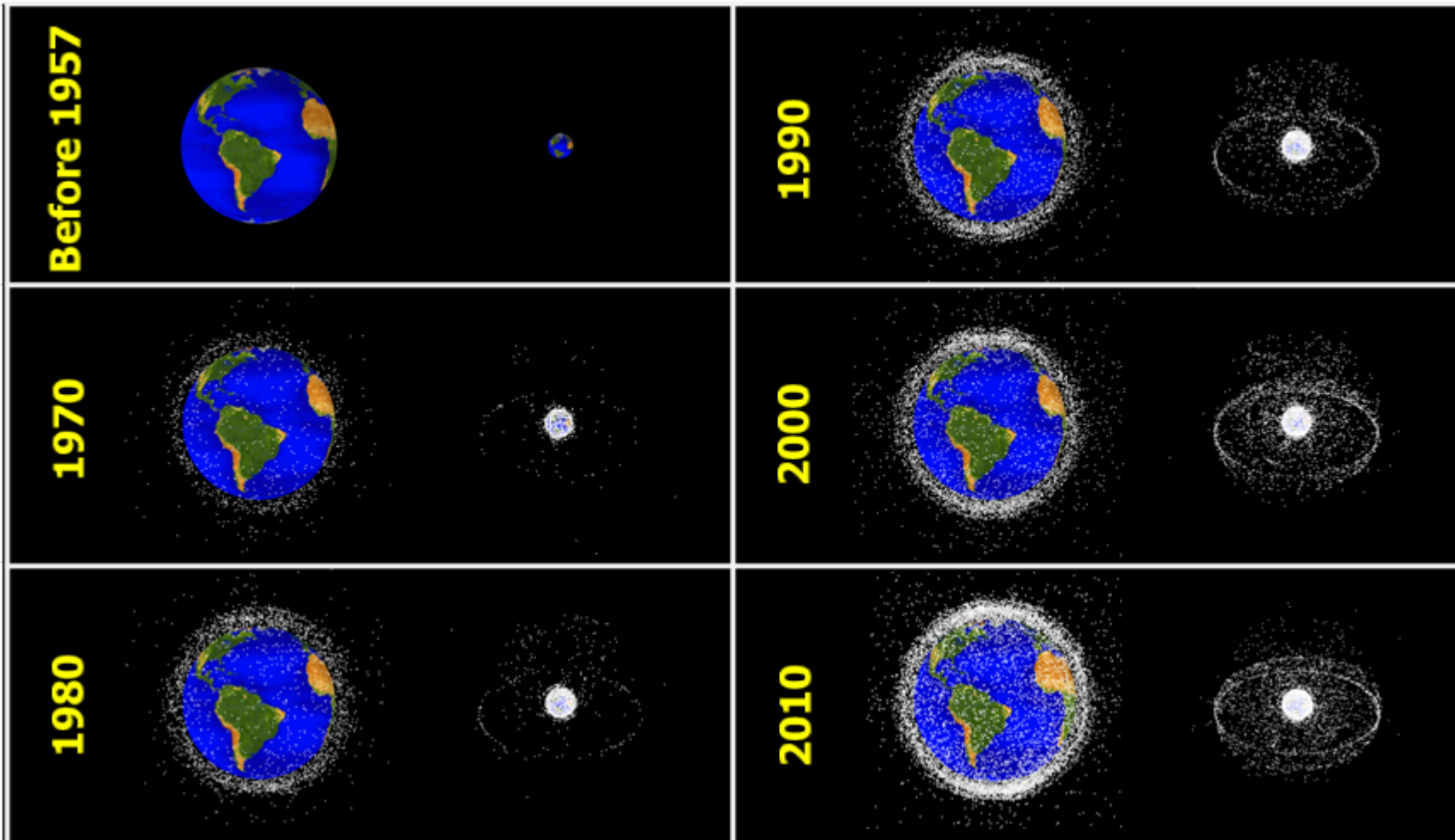
The Space Age

- **The first human-made satellite, Sputnik, was launched to study the atmosphere by the Soviet Union on October 4th, 1957**
- **Since then, more than 4700 launches have been conducted worldwide**
- **Benefits of space activities**
 - Communications
 - Environment monitoring
 - Explorations
 - Technology advancements
 - Many others
- **But...**





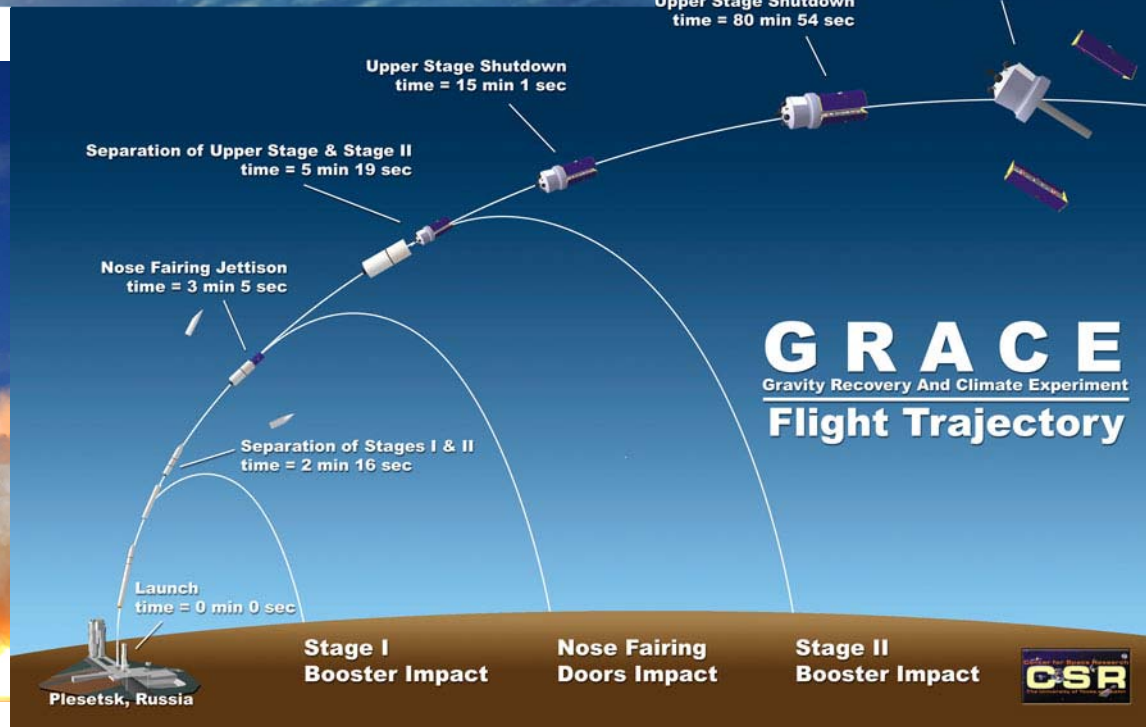
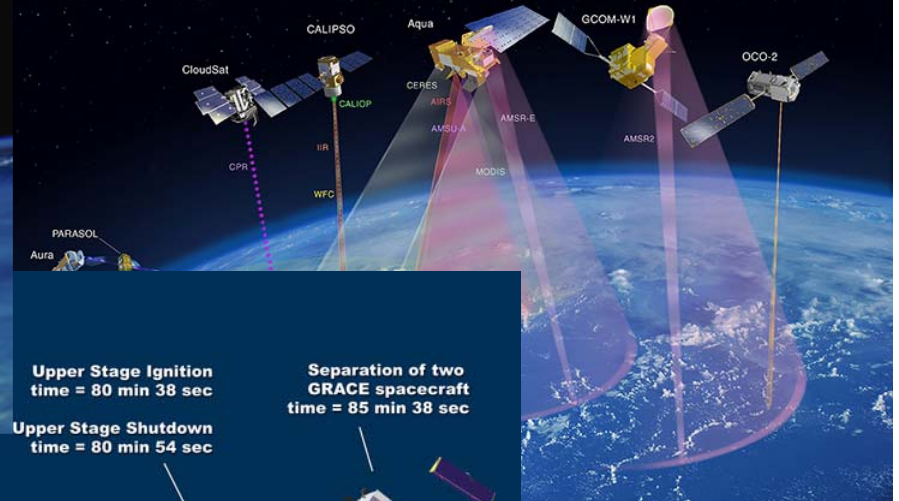
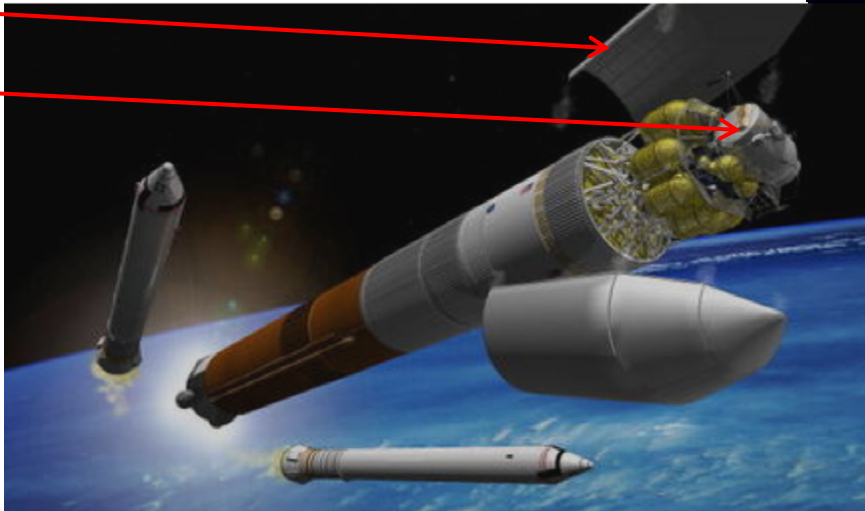
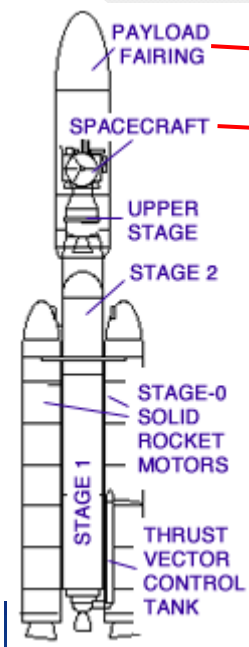
The Historical Orbital Debris Environment



- Only objects in the US Space Surveillance Network (SSN) catalog are shown
- Sizes of the dots are not to scale



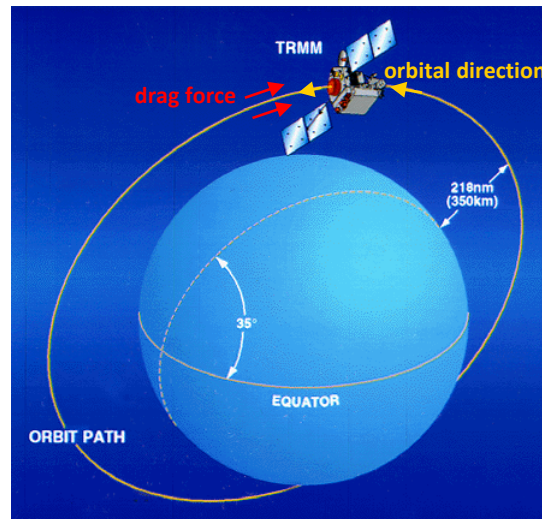
Launching a Satellite into Orbit





Motion in Space (1/2)

- **As a satellite orbits the Earth, it encounters molecules in the thin upper atmosphere. This leads to a small atmospheric drag force in a direction opposite to the flight path**
 - This drag force causes the satellite to slowly decay over time
 - The decay rate depends on the physical property of the satellite and the density of the atmosphere (which is a function of altitude)

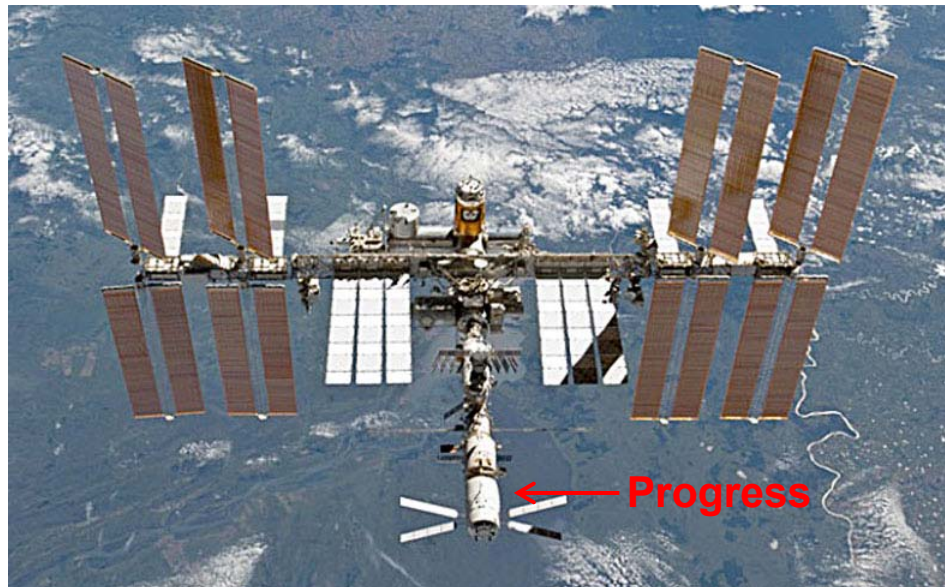


The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and JAXA to monitor and study tropical rainfall. TRMM was launched in 1997 and remains operational today.



Motion in Space (2/2)

- In general, satellites below 400 km altitude could decay in months or less while satellites above 900 km altitude could remain in orbit for centuries or longer
- The International Space Station (ISS) has to fire its thrusters or the thrusters on a visiting vehicle regularly to maintain its orbit

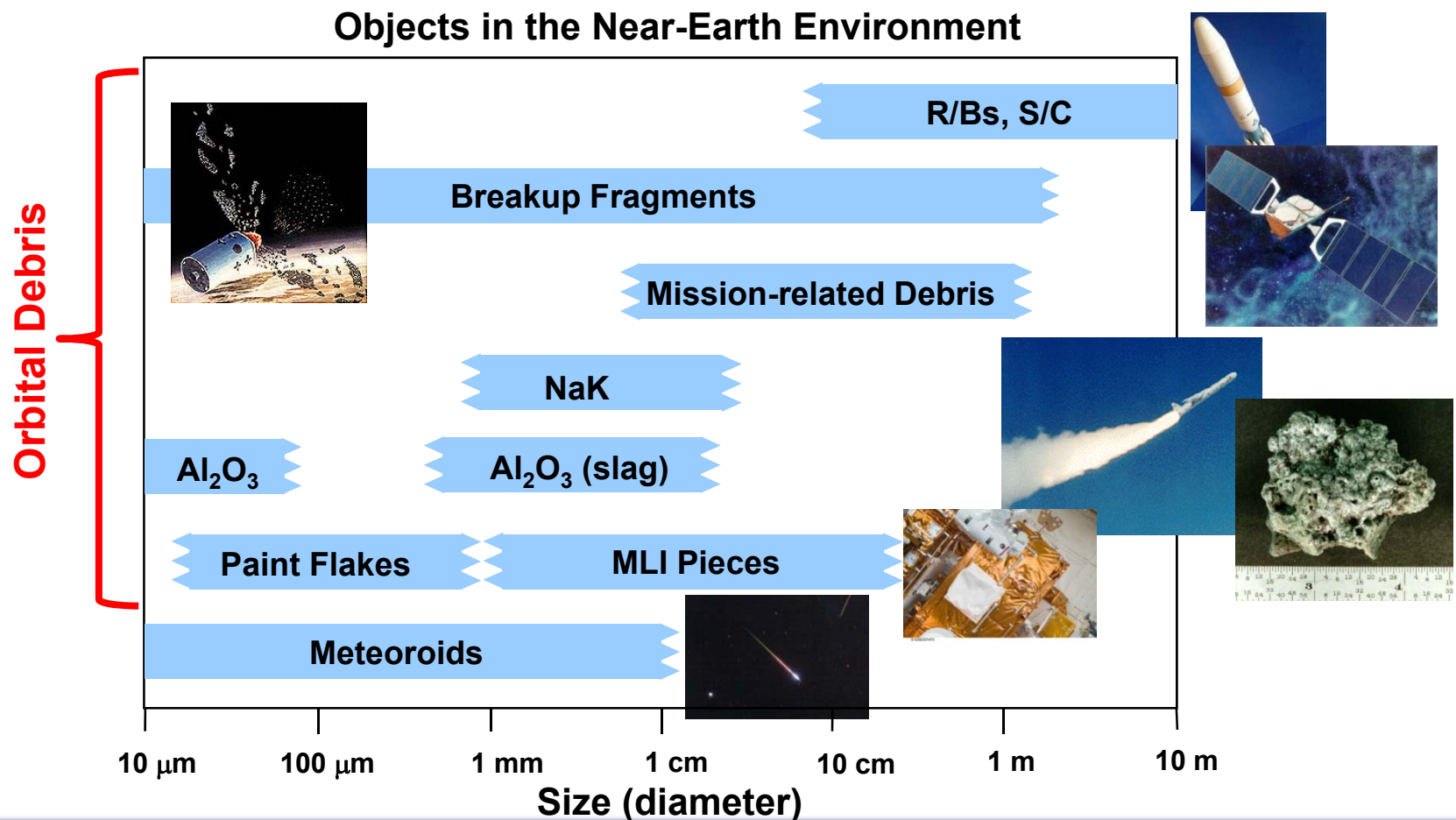


On May 17th, 2013, the visiting Russian Progress M-19M fired its engine for 15 minutes and raised the ISS's orbit by 2.8 km.



What Is Orbital Debris?

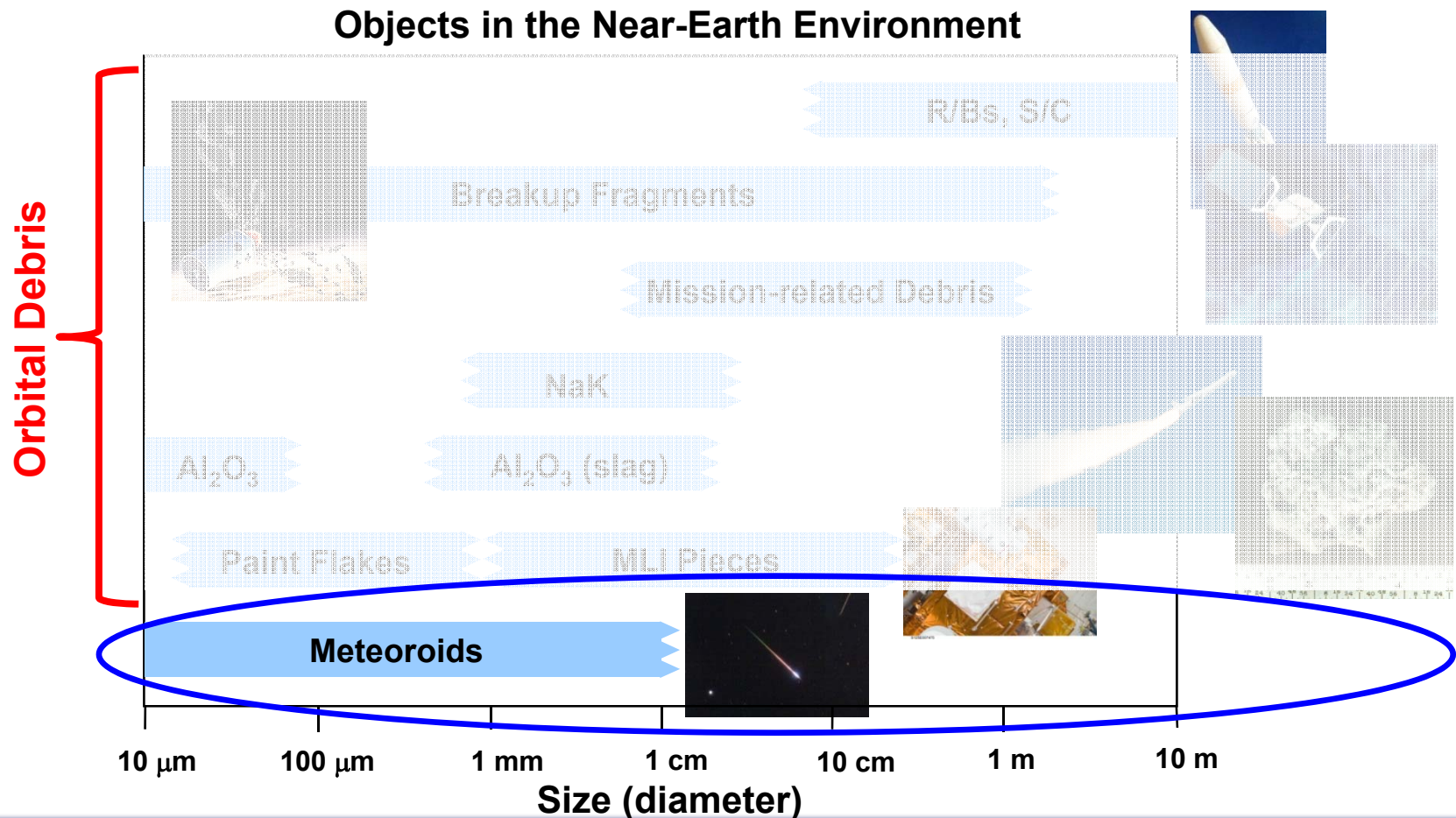
- Orbital debris is any human-made object in orbit about the Earth which no longer serves any useful purpose





What Is Orbital Debris?

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Meteoroids

- **Micrometeoroids (small meteoroids) come from asteroids or comets**

- NASA's definitions

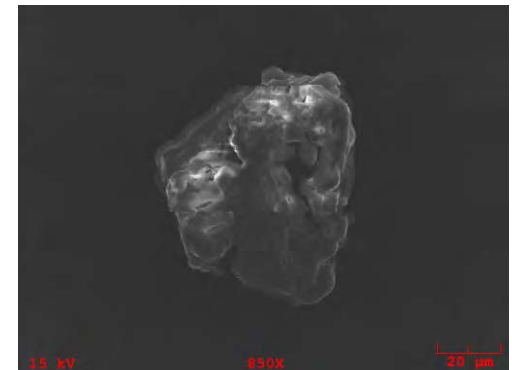
- Orbital debris $\equiv$ human-made debris in space
- Space debris $\equiv$ orbital debris + micrometeoroids



Asteroid Itokawa - target of JAXA's Hayabusa (はやぶさ) mission in 2005



Comet Wild 2 - target of NASA's Stardust mission in 2004

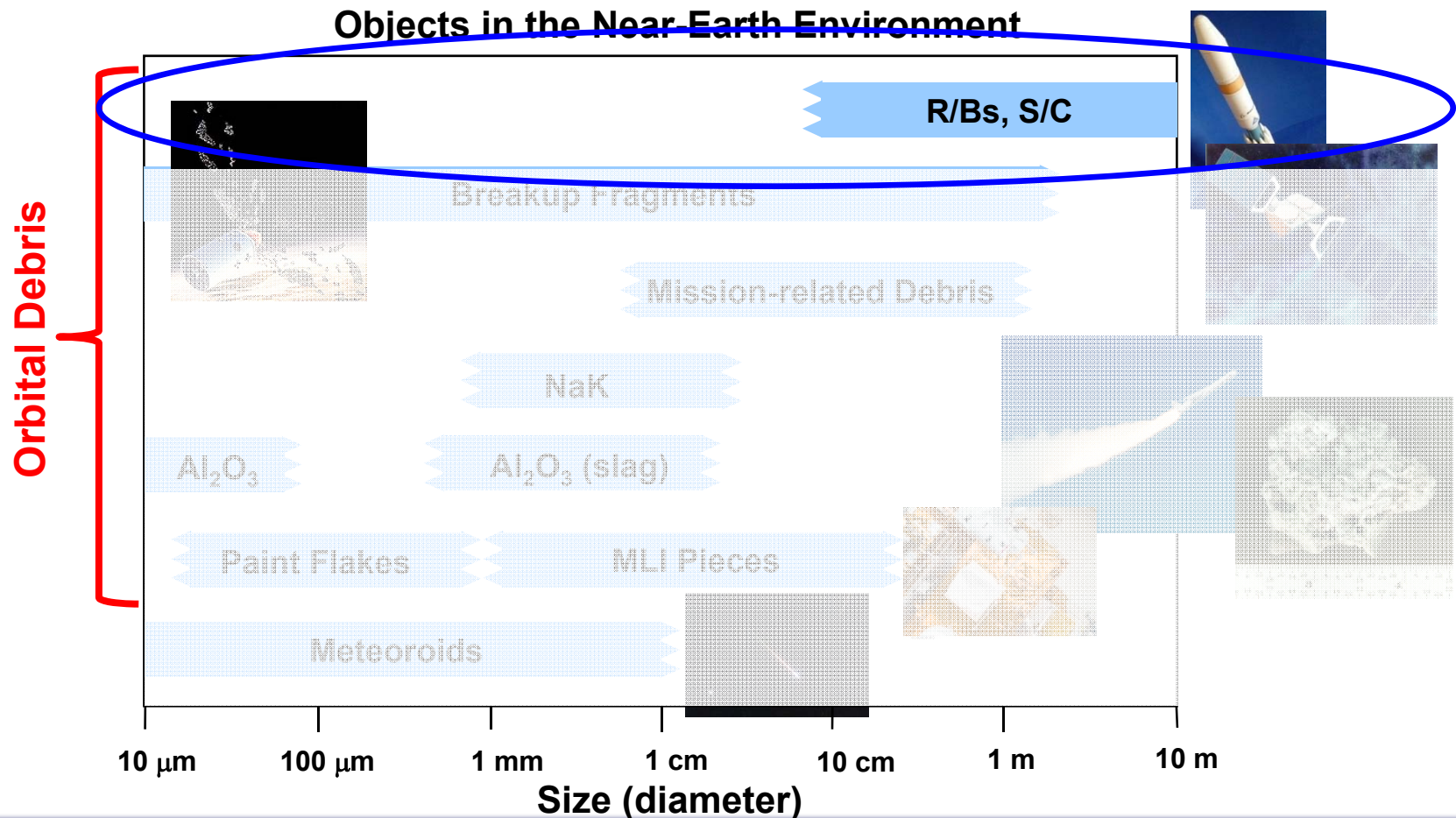


A small micrometeoroid collected by NASA high altitude plane



What Is Orbital Debris?

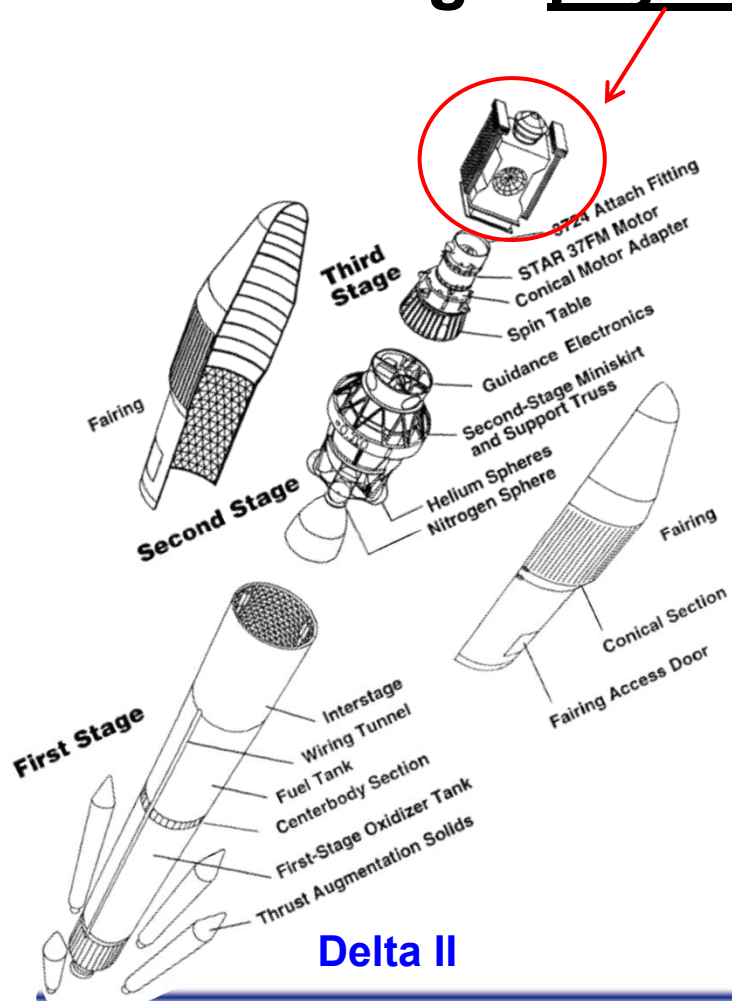
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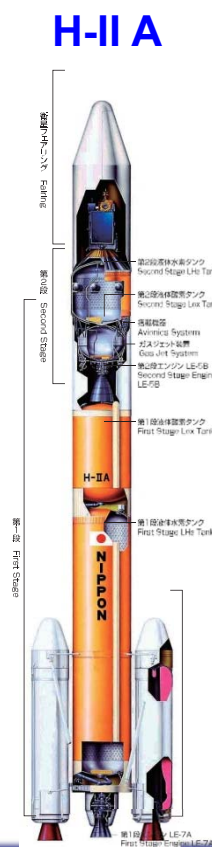


Rocket Bodies (i.e., Upper Stages)

- A rocket is a vehicle carrying propellants capable of launching a payload into space

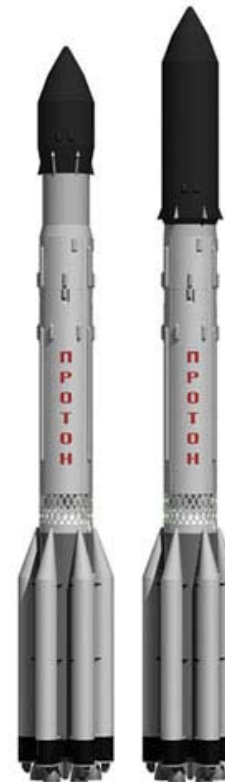


Delta II

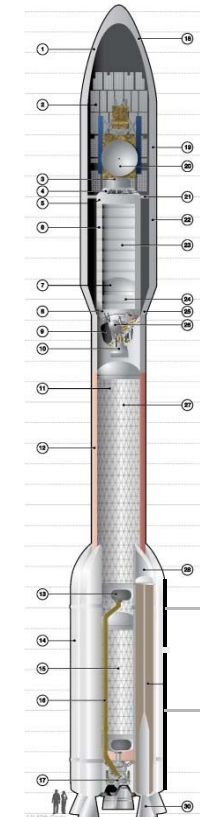


H-II A

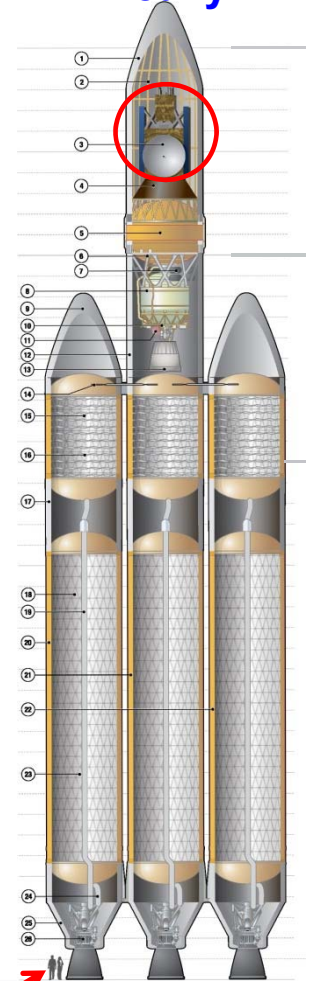
Proton



Atlas V



Delta IV Heavy



regular persons

JCL



Rocket Bodies (R/Bs) in Space

- More than 5400 rocket bodies have been placed into Earth orbit since 1957
- Currently, ~1700 of them remain in space
 - Their masses range from less than 100 kg to more than 9 tons



Cosmos 3M 2nd stage
(2.4 m x 6 m, 1.4 tons)



Zenit 2nd stage
(3.9 m x 11 m, 8.9 tons)



Delta II 2nd stage
(2.4 m x 6 m, 950 kg)



Spacecraft (i.e., Payloads)

- **A spacecraft (payload) is a vehicle carrying operational instruments for specific mission objectives**



ESA's ENVISAT
(790 km altitude, 8.2 tons,
mission ended in 2012)



NASA's TDRS-4
(36,300 km altitude, 2.1 tons,
mission ended in 2011)

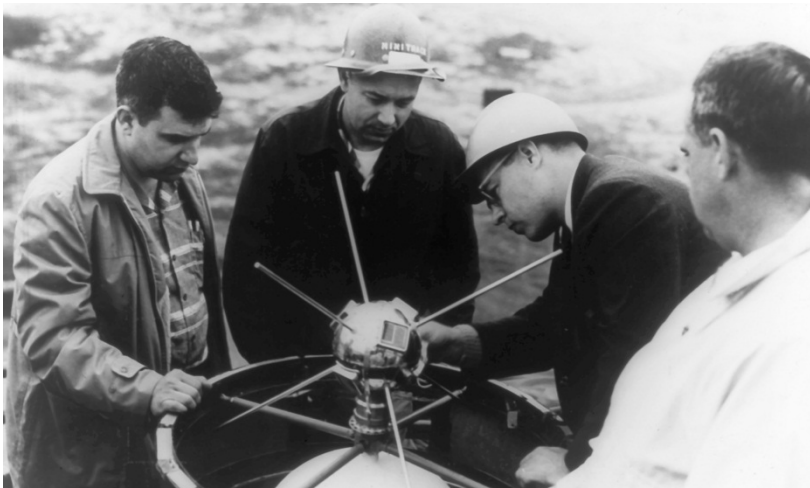


NASA's HST
(560 km altitude, 11 tons,
operational)



Spacecraft (S/C) in Space

- **More than 6800 spacecraft have been placed into Earth orbit since 1957**
- **Currently, ~3500 spacecraft remain in Earth orbit**
 - Approximately 1100 of them are operational
 - The remaining ~2400 have become orbital debris!
 - **As of July 2013, the oldest spacecraft in space is “Vanguard 1” which was launched in 1958**



NRL scientists mounted Vanguard 1 in the rocket

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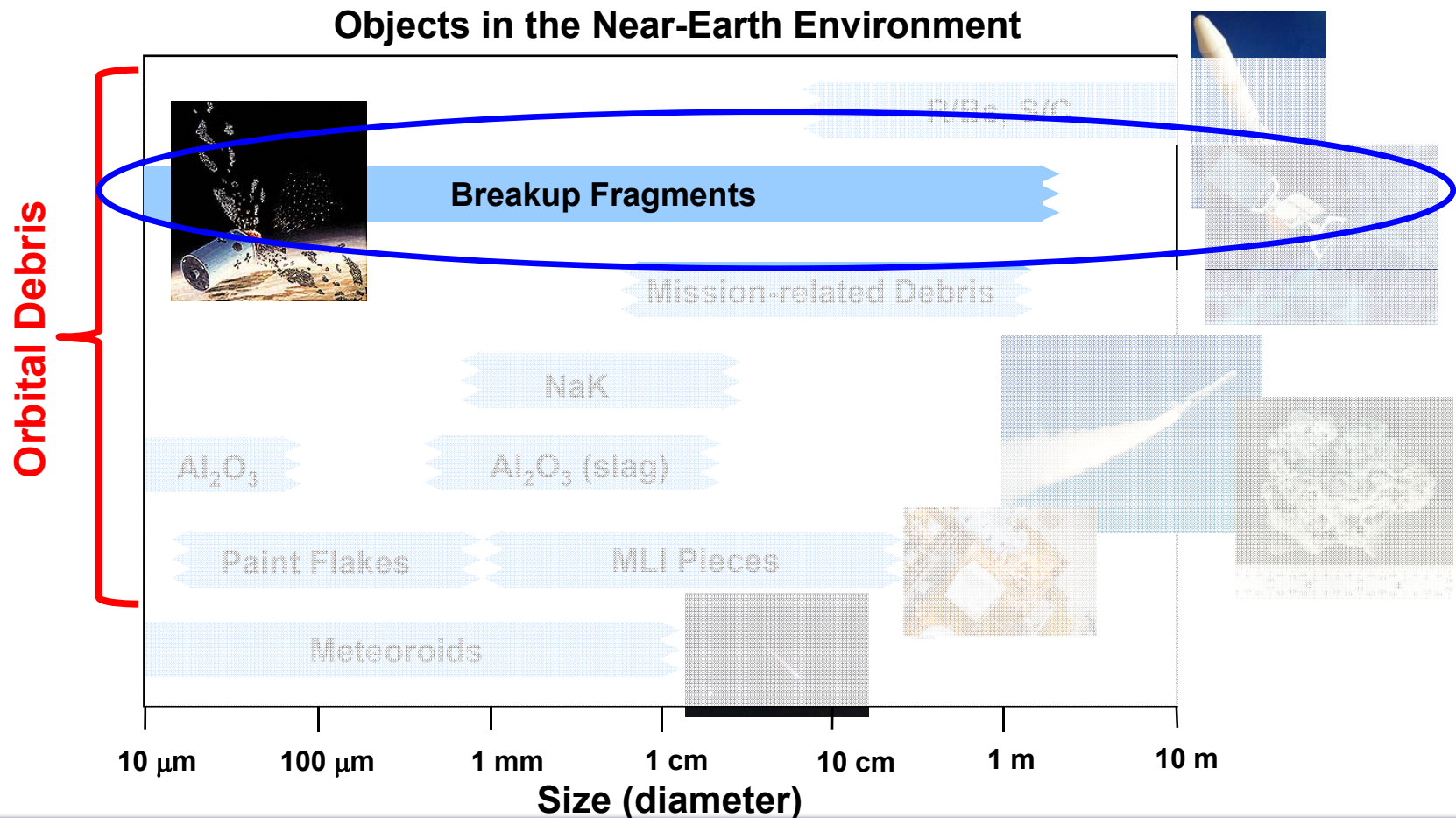


Launch of Vanguard 1



What Is Orbital Debris?

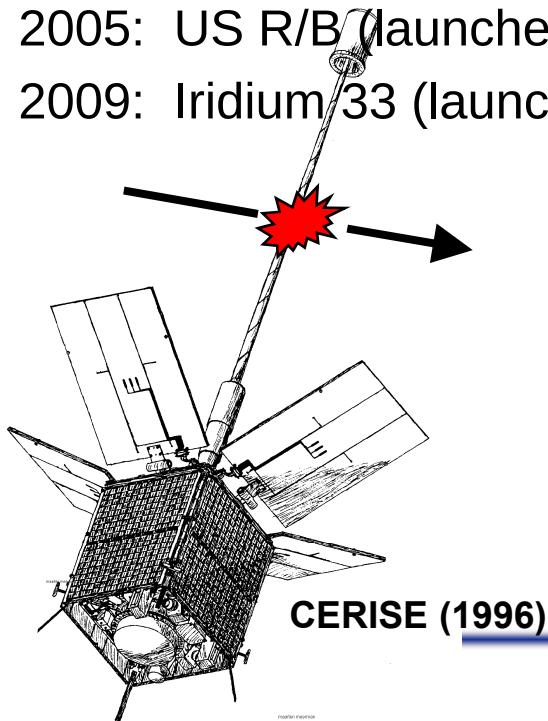
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Satellite Breakups

- **More than 210 explosions have been documented since 1957**
- **Four accidental collisions among the cataloged objects have occurred so far**
 - 1991: Russian S/C (launched in 1988) ↔ Russian fragment
 - 1996: French S/C (launched in 1995) ↔ French fragment
 - 2005: US R/B (launched in 1974) ↔ PRC fragment
 - 2009: Iridium 33 (launched in 1997) ↔ Cosmos 2251 (launched in 1993)

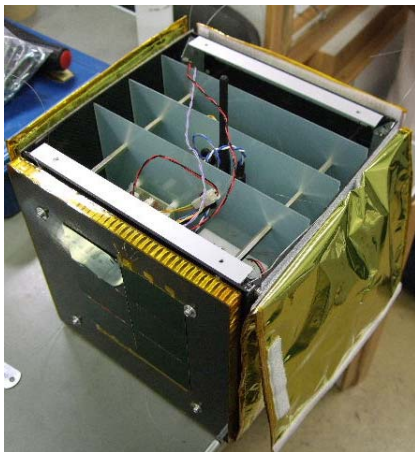


Laboratory-Based Satellite Collision Experiments



- The NASA Orbital Debris Program Office has collaborated with Professor Toshiya Hanada (Kyushu University) on seven laboratory-based satellite impact experiments

(Target: fully-equipped 20-cm cube-sat, 3-cm Al projectile @ 1.8 km/sec)





Examples of Explosions

- **Briz-M (4th stage of Russian Proton Launch Vehicle)**
 - 4 m diameter, 2.65 m length, 2.6 tons dry mass
 - Three explosions since 2007
 - **2007 (2006-006B): 495 km × 14,705 km, 51.5°**
 - **2010 (2008-011B): 645 km × 26,565 km, 48.9°**
 - **2012 (2012-044C): 265 km × 5015 km, 49.9°**
 - Possible cause: explosion of the remaining propellant after failed separation



Main propulsion system
(5.2 tons propellant)

Auxiliary propellant tank
(APT, 17.6 tons propellant)



How Much Orbital Debris Is In Space?



How Much Junk Is Currently Up There?

Softball size or larger (≥ 10 cm): ~22,000
(most of them are tracked by the US Space Surveillance Network)



Marble size or larger (≥ 1 cm): ~500,000



Dot or larger (≥ 1 mm): >100,000,000
(a grain of salt)

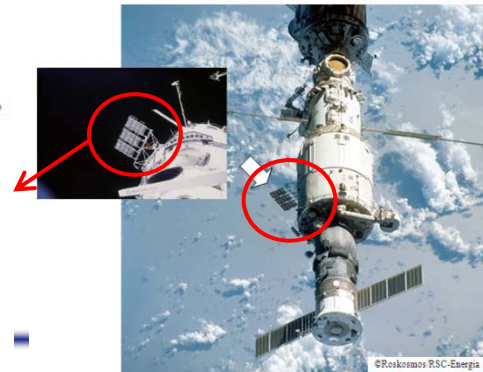
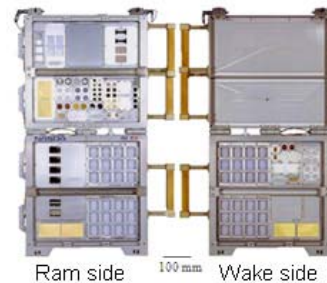
- Total mass: ~6300 tons LEO-to-GEO (~2700 tons in LEO)
- Due to high impact speed in space (~10 km/sec in LEO), even sub-mm debris pose a realistic threat to human spaceflight and robotic missions



Orbital Debris Observations

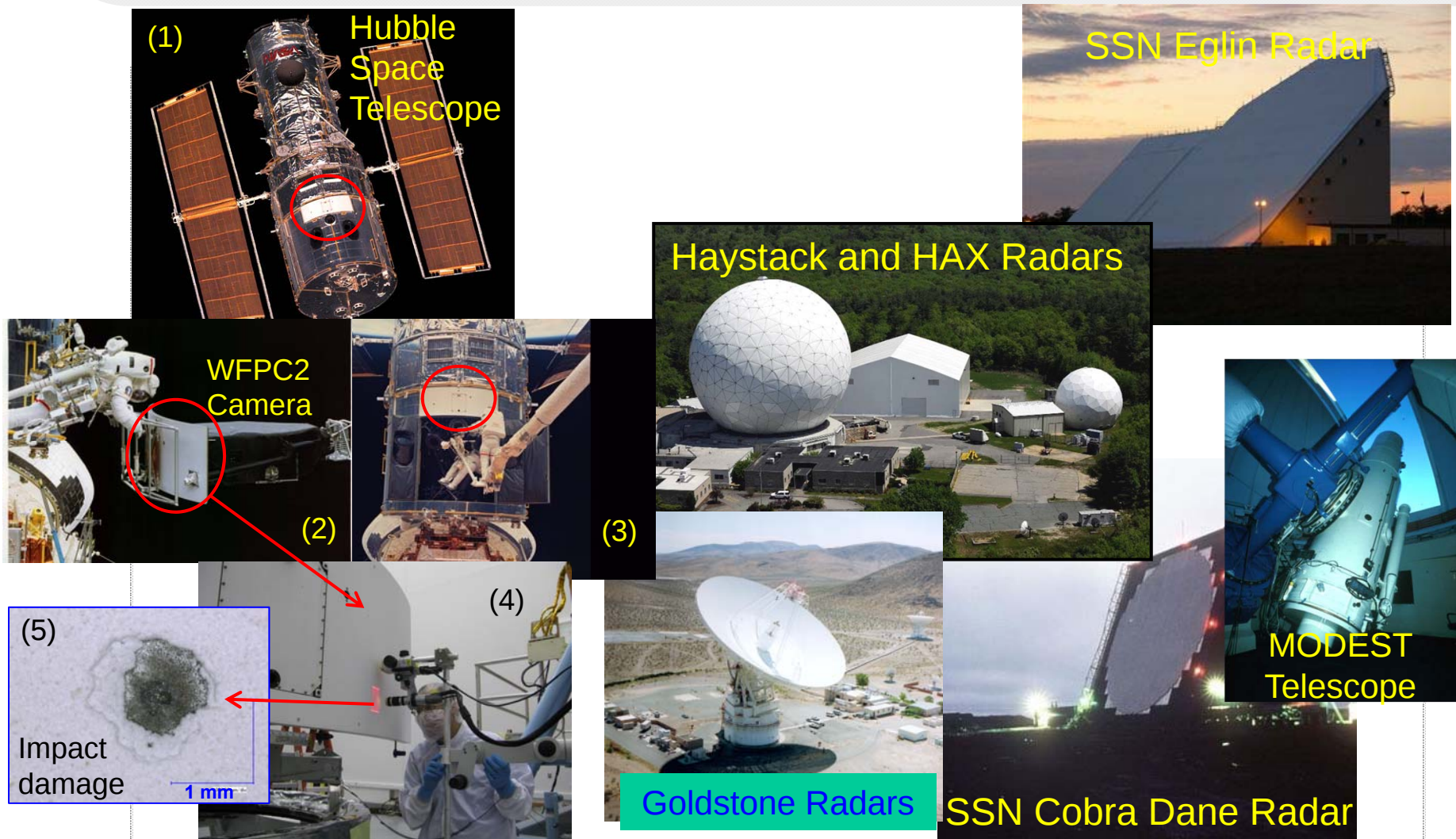
- **Ground-based radars and telescopes are used to detect and track the largest orbital debris**
 - The U.S. Space Surveillance Network (SSN) radars/telescopes can detect orbital debris as small as 10 cm in LEO and as small as 1 m in GEO
 - The most powerful NASA Goldstone radars can detect orbital debris as small as 2 mm in size at a distance of 1000 km
- **Space-based in situ sensors and returned surfaces**
 - Orbital debris smaller than a few mm in size can only be detected by space-based sensors or by the inspection of surfaces returned from space

JAXA's Micro-Particles Capturer (MAPC)





Examples of Orbital Debris Sensors



10 μm

100 μm

1 mm

1 cm

10 cm

1 m

10 m

Orbital Debris Diameter



Danger of Orbital Debris



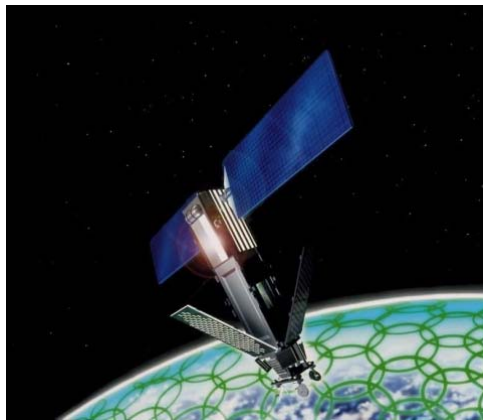
The Big Sky Is Getting Crowded

- **Four accidental collisions between cataloged objects have been documented**
 - The collision between Cosmos 2251 and the operational Iridium 33 in 2009 underlined the potential of the Kessler Syndrome
- **The U.S. Joint Space Operations Center (JSpOC) is currently providing conjunction assessments for all operational S/C**
 - JSpOC issues ~10 to 30 conjunction warnings on a daily basis, and more than 100 collision avoidance maneuvers were carried out by satellite operators per year
- **The International Space Station (ISS) has conducted 16 debris avoidance maneuvers since 1999**



Threat from Large Orbital Debris

- **In general, collision with a 10 cm or larger object in LEO will lead to a complete breakup of the vehicle**
 - A retired Russian satellite Cosmos 2251 and a US operational satellite Iridium 33 accidentally collided with each other ~790 km altitude on February 10th, 2009. Both satellites were destroyed and generated ~2100 large trackable fragments and tens of thousands of smaller debris.



**Iridium33
(560 kg)**

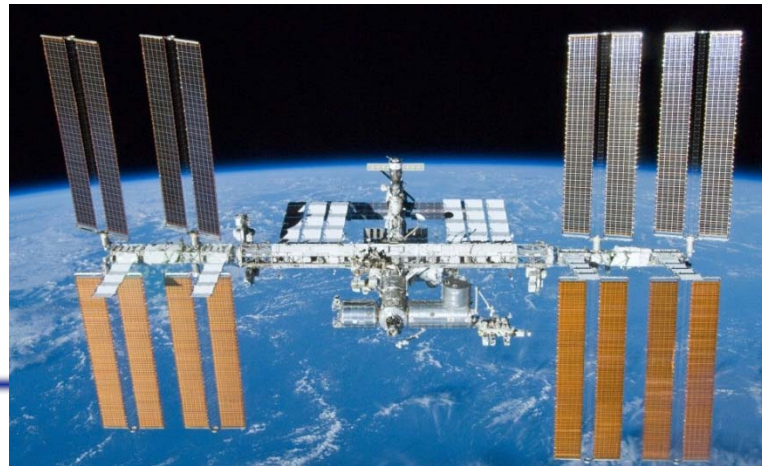


**Cosmos 2251
(900 kg)**



The International Space Station (1/2)

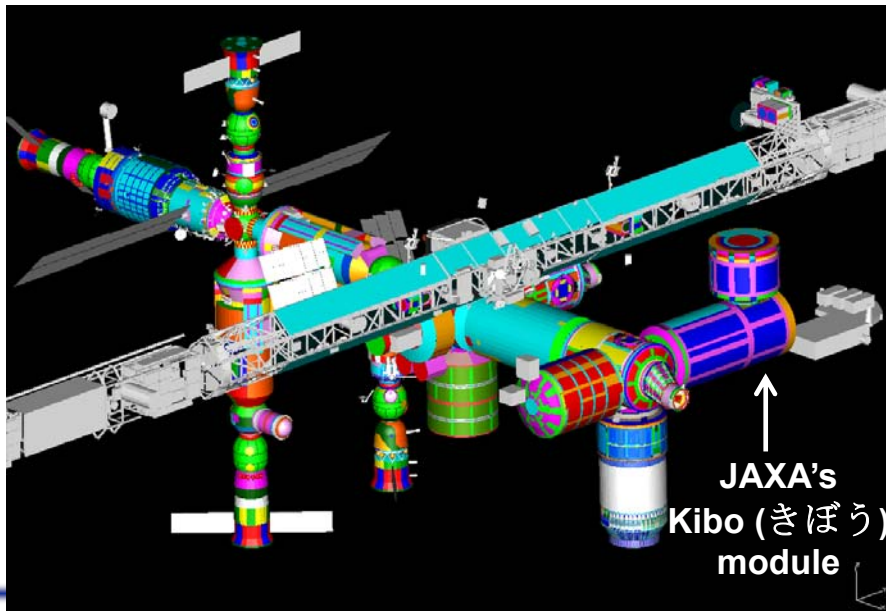
- **During 2012, three debris avoidance maneuvers were conducted by the ISS, the most in any year**
 - January 13th: to avoid a trackable Iridium 33 debris
 - January 28th: to avoid a trackable FY-1C debris
 - October 31st: to avoid a trackable Iridium 33 debris
- **On March 24th, 2012 the crew of the ISS was forced to retreat to Soyuz spacecraft**
 - A Cosmos 2251 fragment was predicted to pass too close and insufficient time was available to perform a collision avoidance maneuver





The International Space Station (2/2)

- **The ISS is equipped with various MMOD impact protection shields**
 - The U.S. segments of the ISS are protected against orbital debris approximately 1.4 cm and smaller
 - The threat for the ISS comes from orbital debris too small to be tracked by the SSN but large enough to penetrate the protection shields

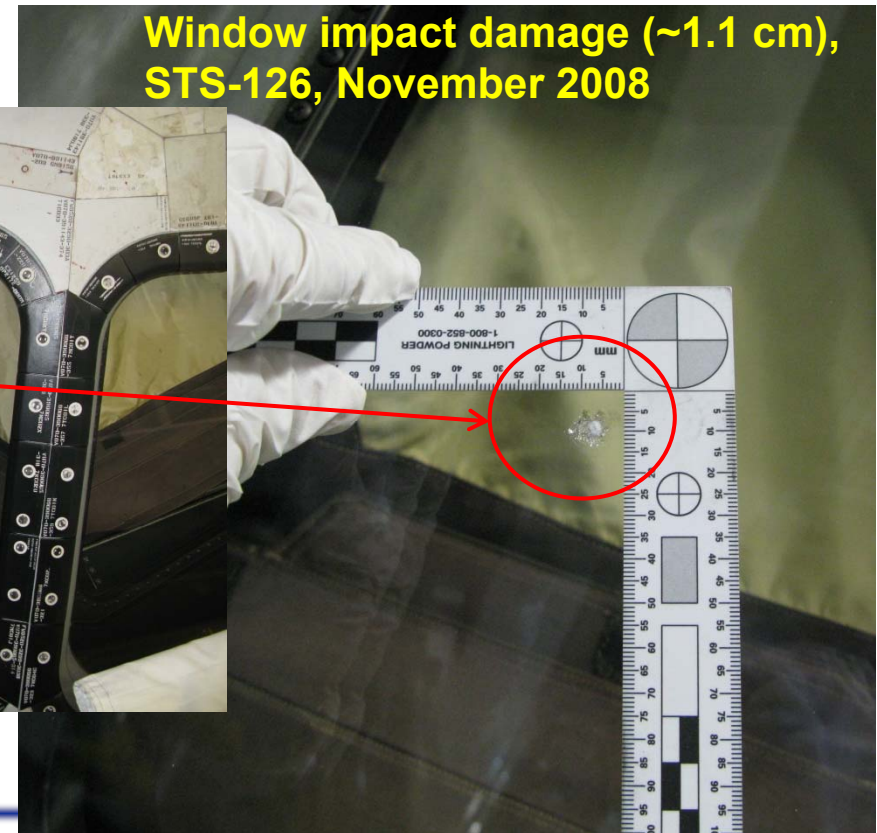


The ISS MMOD shielding models - Each color represents a different MMOD shield configuration. About 500 different shields protect ISS modules and external pressure vessels.



Threat from Small Orbital Debris (1/2)

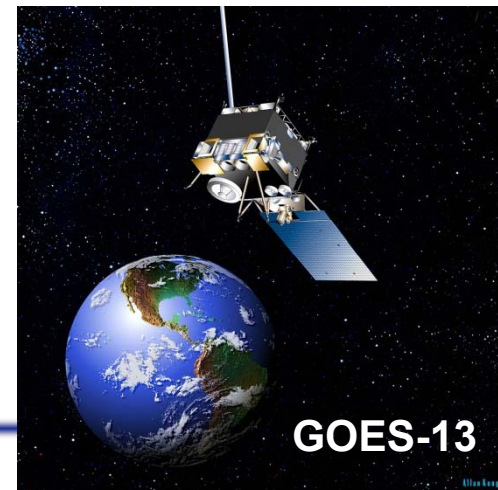
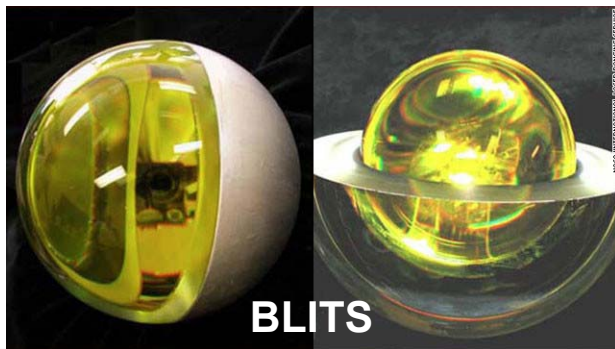
- Near the end of the Space Shuttle Program, on average two window panels were replaced after each mission due to damage from MMOD impacts





Threat from Small Orbital Debris (2/2)

- **Satellite anomalies are mission-degrading or mission-ending events to operational spacecraft**
- **Impact damage by small MMOD particles could be responsible for many anomalies. Examples include:**
 - A Russian retro reflector, Ball Lens In The Space (BLITS) was damaged and shed a piece of trackable debris in January 2013
 - A U.S. Geostationary Operational Environmental Satellite 13 (GOES-13) experienced an attitude drift of >2 deg/sec in May 2013. Fortunately there was no permanent damage and GOES-13 was returned to normal operations in June.





Satellite Reentries

- **More than 400 R/Bs, S/C, and other debris reentries were recorded by the U.S. SSN during 2012**
 - The oldest satellite to reenter was NASA's Explorer 8, which was launched in 1960 (initial orbit: 417 km × 2288 km; 41 kg)
 - Uncontrolled reentries accounted for a total mass of >100 metric tons from 57 R/Bs and S/C
 - **For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 1 in 10,000 (U.S. Government)**
 - A total of 14 S/C and 11 R/Bs executed controlled reentries



Delta II propellant tank
(Georgetown, TX, 1997)



Titanium casting of STAR-48B SRM
(Saudi Arabia, 2001)



Titanium casting of STAR-48B SRM
(Argentina, 2004)



Ariane 4 3rd stage tank
(Brazil, 2012)

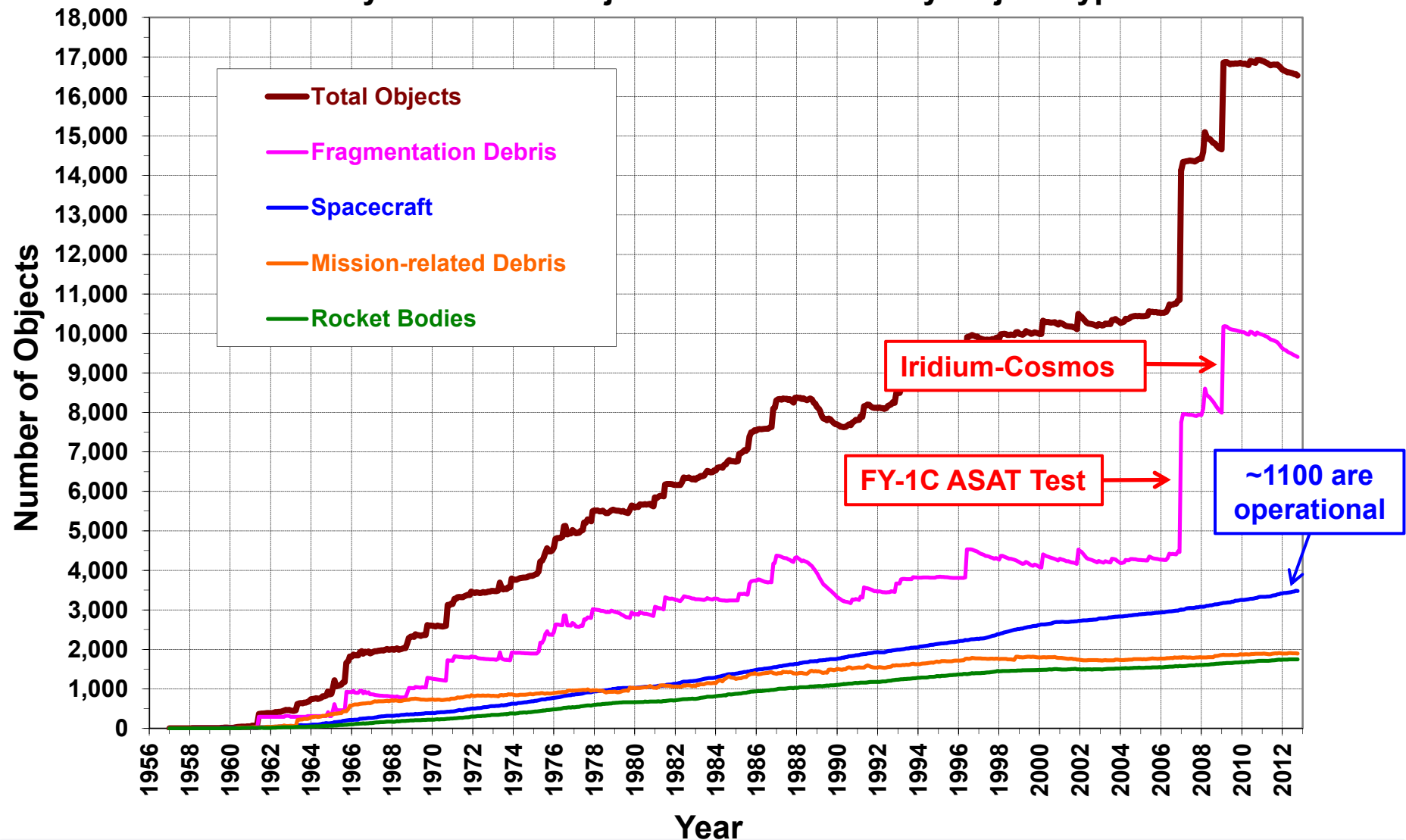


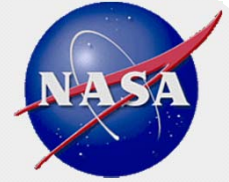
Challenges To Preserve The Near-Earth Space Environment



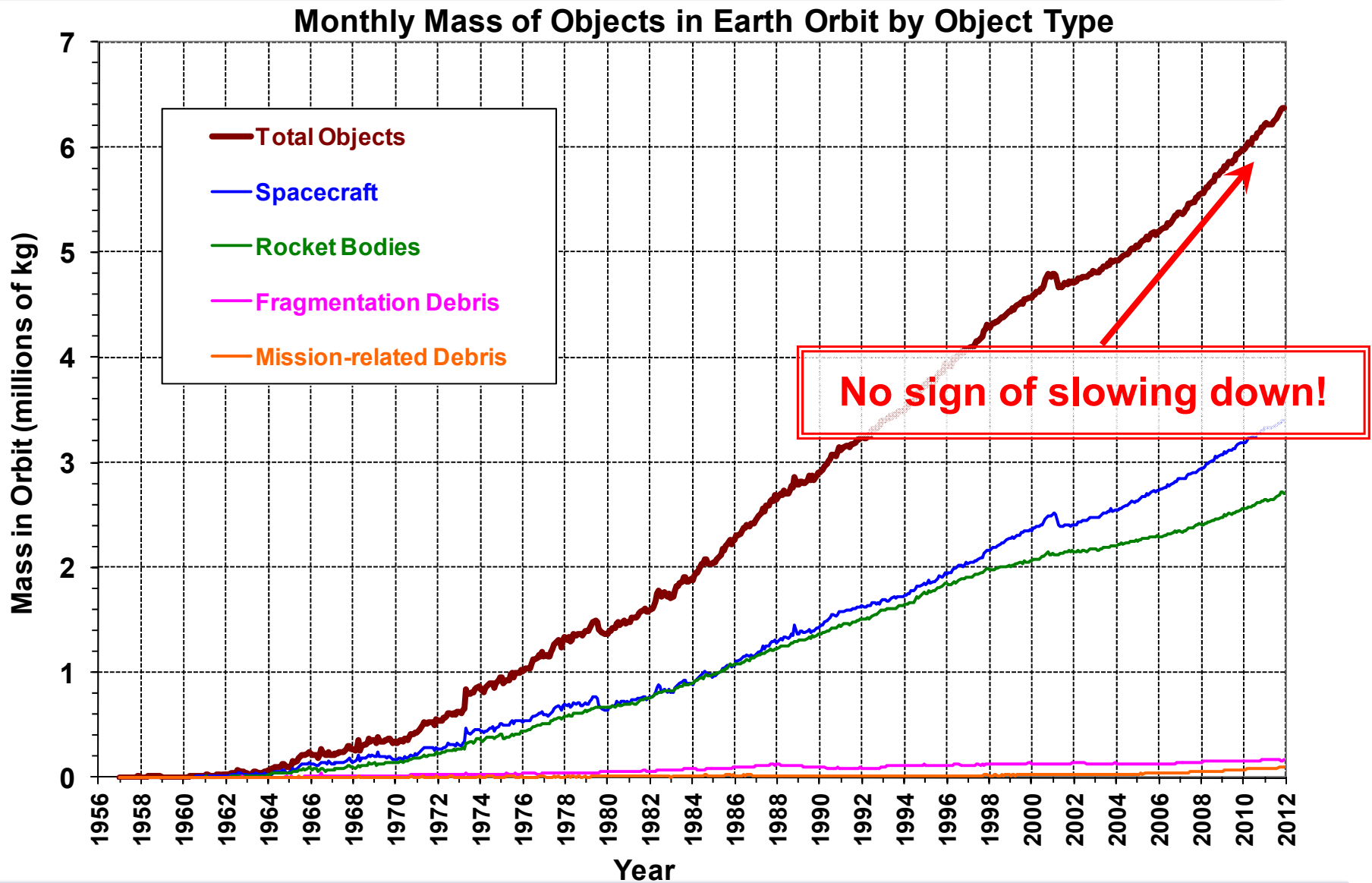
Growth of the Cataloged Populations

Monthly Number of Objects in Earth Orbit by Object Type





Mass in Orbit





Future Orbital Debris Environment

- **Orbital debris scientists from major international space agencies, including JAXA and NASA, have worked together to predict the trend of the future environment. A summary presentation was given to the United Nations in February 2013.**
 - The orbital debris population in LEO **will continue to increase**
 - Catastrophic collisions will continue to occur every 5 to 9 years
- **To limit the growth of the future debris population and to better protect future spacecraft, active debris removal, should be considered.**



Orbital Debris Environment Remediation

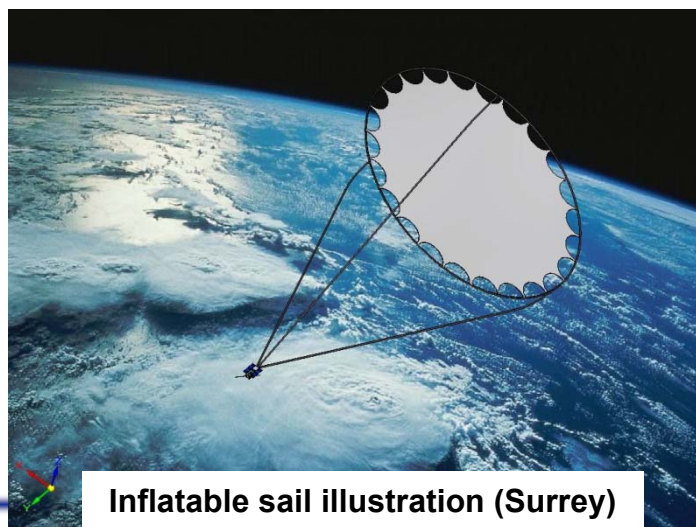
- It is difficult and expensive to launch and deploy a satellite.
- How difficult will it be to fix the orbital debris problem?





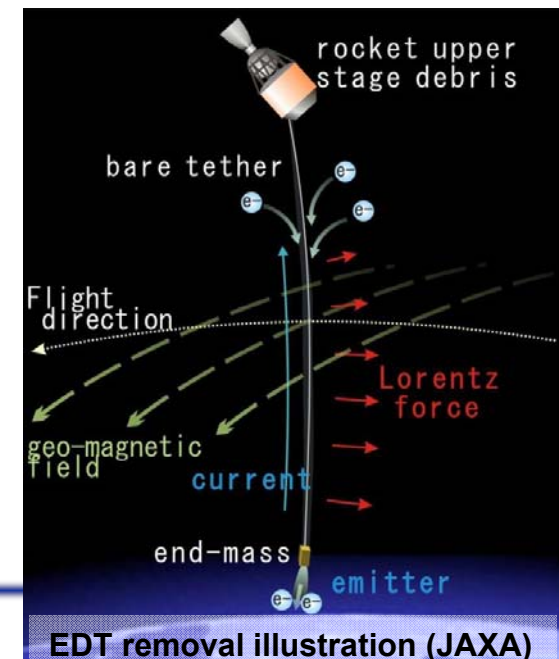
Large Debris Removal

- **Rocket bodies and retired spacecraft**
 - These large and massive (up to 9 metric tons) objects are the source of future fragmentation debris
 - Studies have shown that the removal of ~5 high priority objects per year can stabilize the LEO debris environment
 - Concepts for removal proposed by various research groups include electrodynamic tethers (EDT), drag enhancement devices, solar electric propulsion, etc.



Inflatable sail illustration (Surrey)

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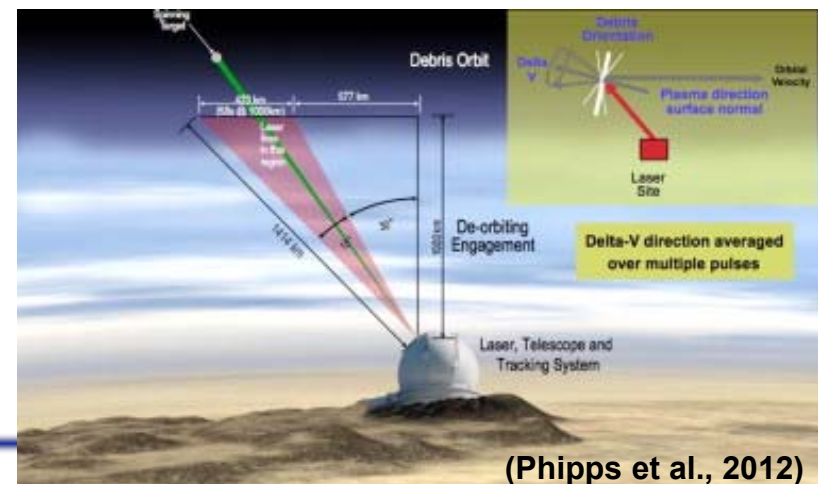
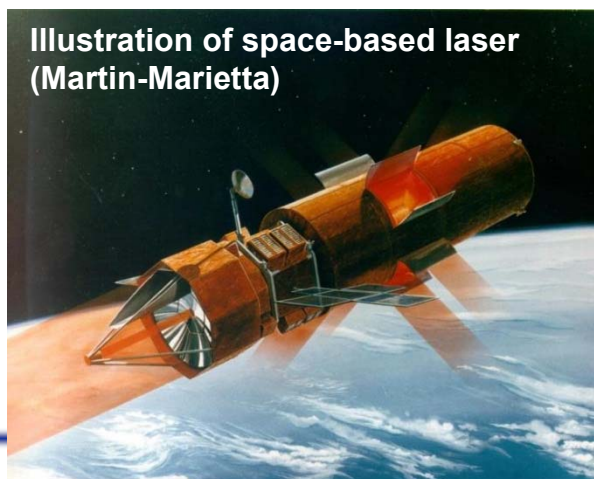
EDT removal illustration (JAXA)

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Small Debris Removal

- **Orbital debris ~mm to ~cm in size**
 - They are too small to be tracked by the U.S. SSN or other space surveillance systems, but are large enough to damage operational S/C
 - The main threat for operational S/C comes from these small debris
 - The population is estimated to be about 500,000
 - Concepts for removal proposed by various research groups include large-area collectors, laser systems, etc.





Preserving the Environment for Future Generations

- The international space community should work together to (1) limit the generation of new debris and (2) consider the option to remove existing objects
- Scientists and engineers need to come up with innovative concepts and technologies to address the orbital debris challenges

